



US007713866B2

(12) **United States Patent**  
**Moon et al.**

(10) **Patent No.:** **US 7,713,866 B2**  
(45) **Date of Patent:** **May 11, 2010**

(54) **SEMICONDUCTOR DEVICES AND METHODS OF MANUFACTURE THEREOF**

(75) Inventors: **Bum Ki Moon**, LaGrangeville, NY (US); **Danny Pak-Chum Shum**, Poughkeepsie, NY (US); **Moosung Chae**, Poughkeepsie, NY (US)

(73) Assignee: **Infineon Technologies AG**, Munich (DE)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 153 days.

(21) Appl. No.: **11/602,885**

(22) Filed: **Nov. 21, 2006**

(65) **Prior Publication Data**

US 2008/0116576 A1 May 22, 2008

(51) **Int. Cl.**  
**H01L 21/4763** (2006.01)

(52) **U.S. Cl.** ..... **438/643; 438/638; 257/E21.584**

(58) **Field of Classification Search** ..... **438/643, 438/638, 687**

See application file for complete search history.

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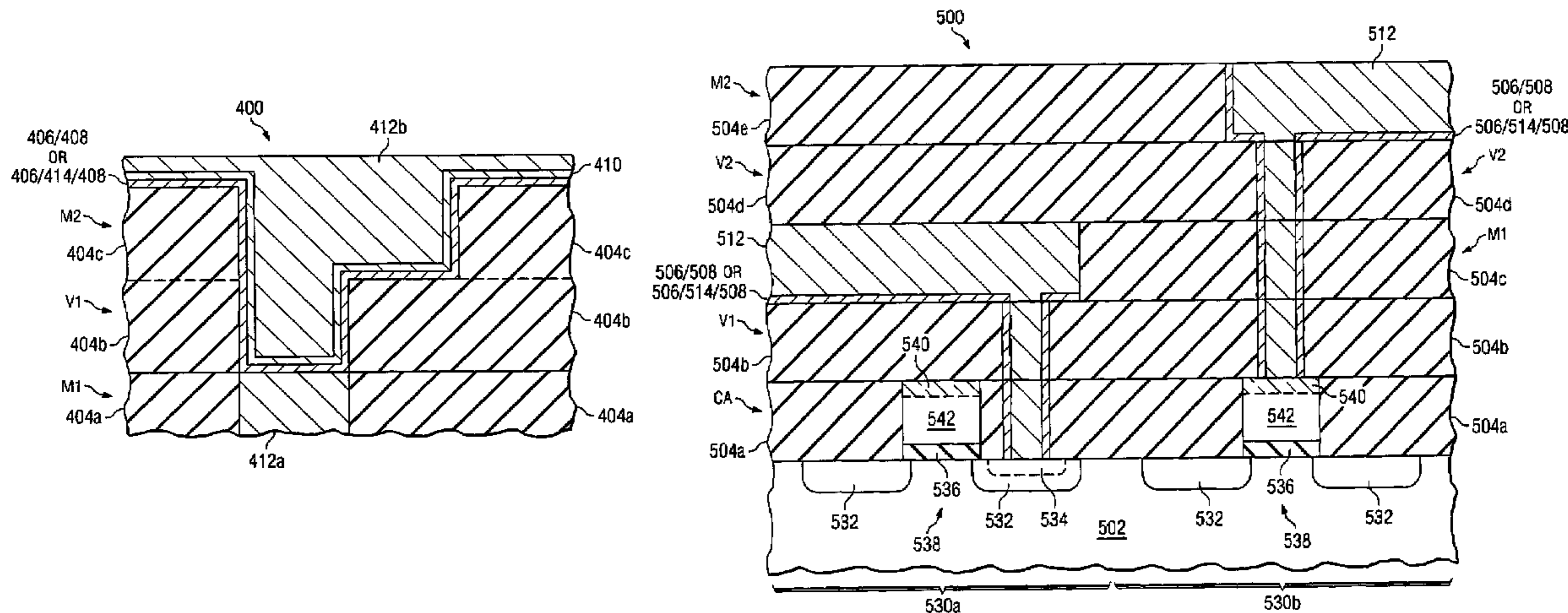
*Assistant Examiner*—Nga Doan

(74) *Attorney, Agent, or Firm*—Slater & Matsil, L.L.P.

(57) **ABSTRACT**

Semiconductor devices and methods of manufacture thereof are disclosed. A preferred embodiment comprises a method of forming a barrier layer. The method of forming the barrier layer includes providing a workpiece, forming a first material layer over the workpiece, the first material layer comprising a nitride-based metal compound. A second material layer is formed over the first material layer. The second material layer comprises Ta or Ti. The barrier layer comprises the first material layer and at least the second material layer.

**21 Claims, 3 Drawing Sheets**



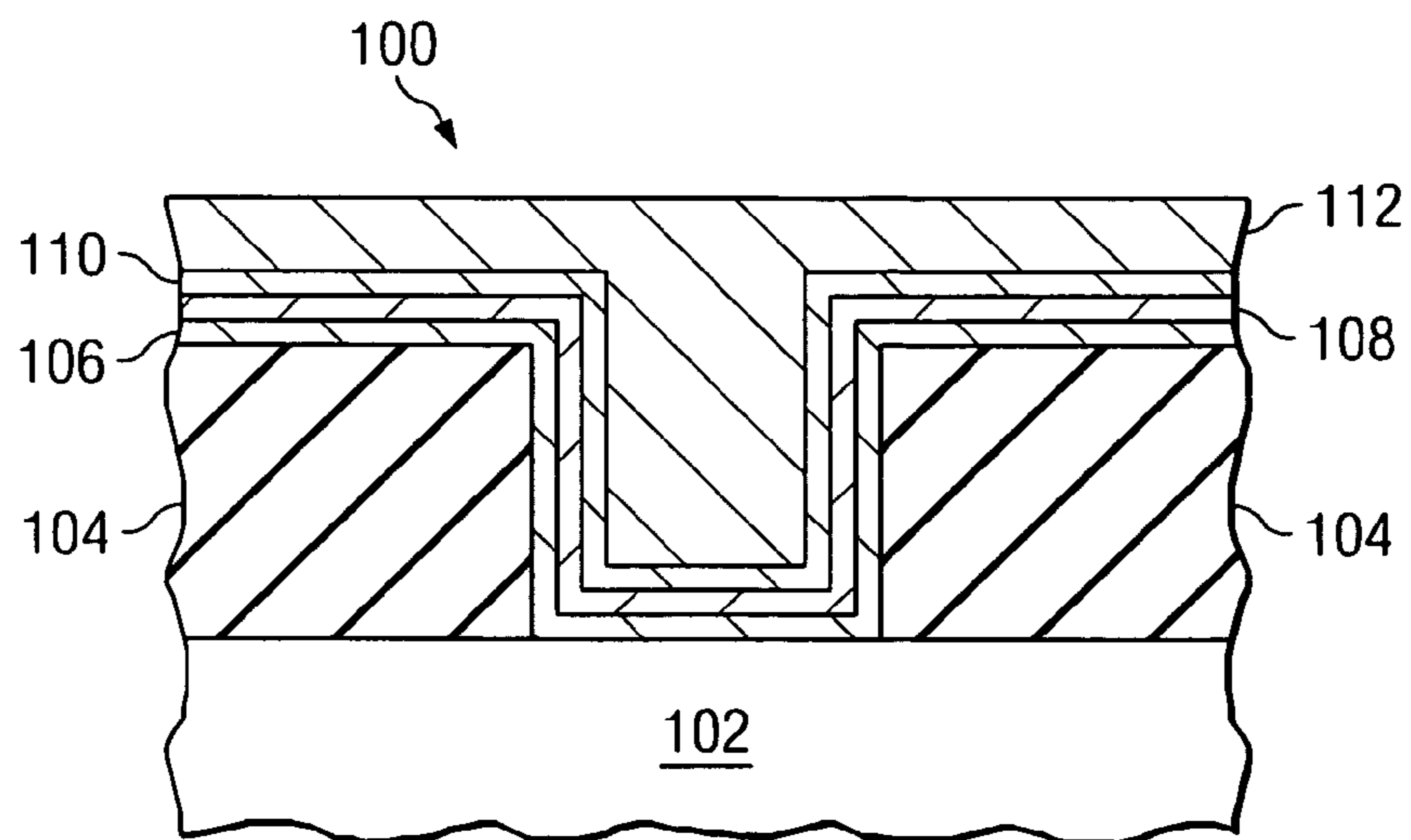


FIG. 1

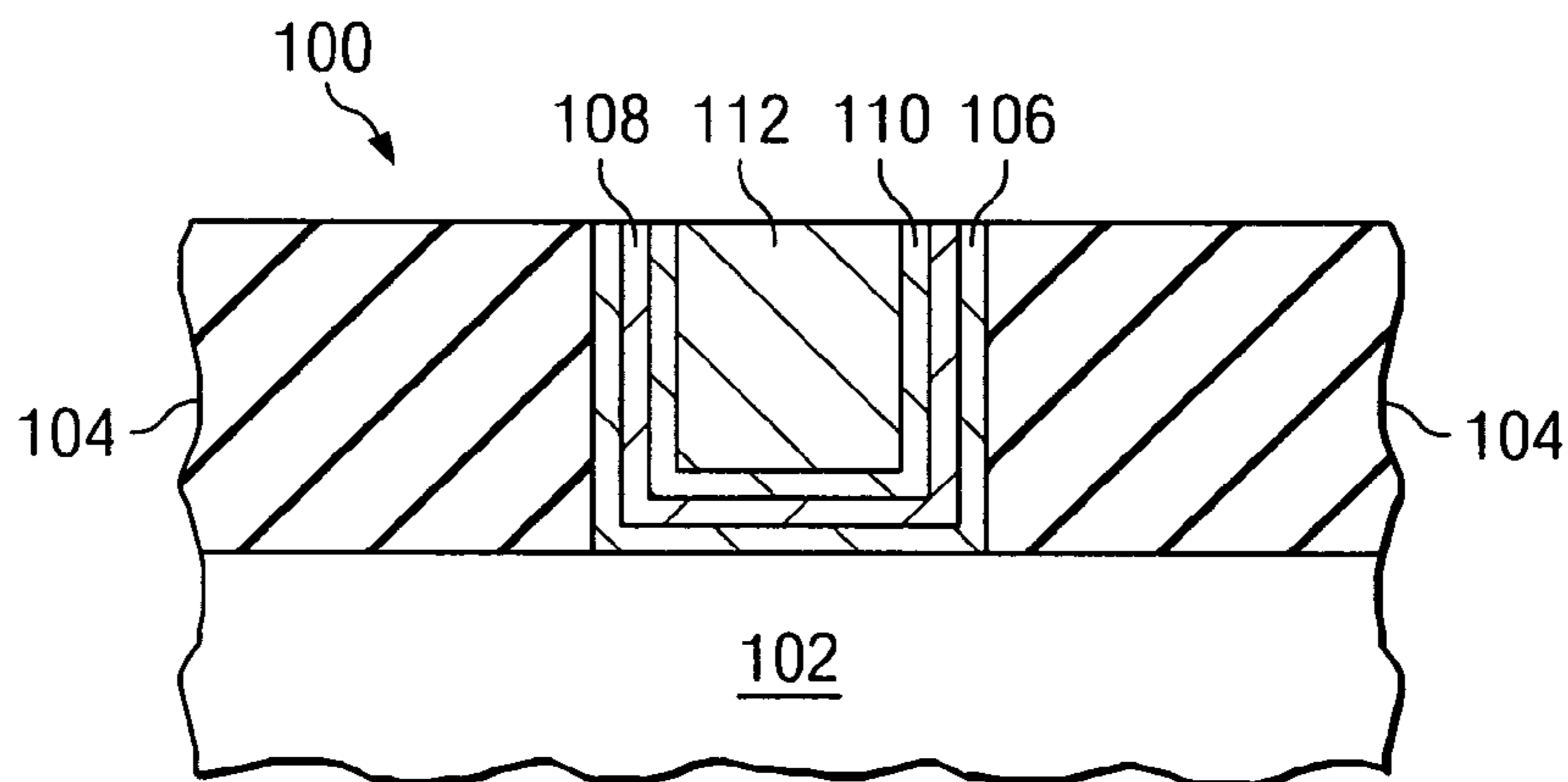


FIG. 2

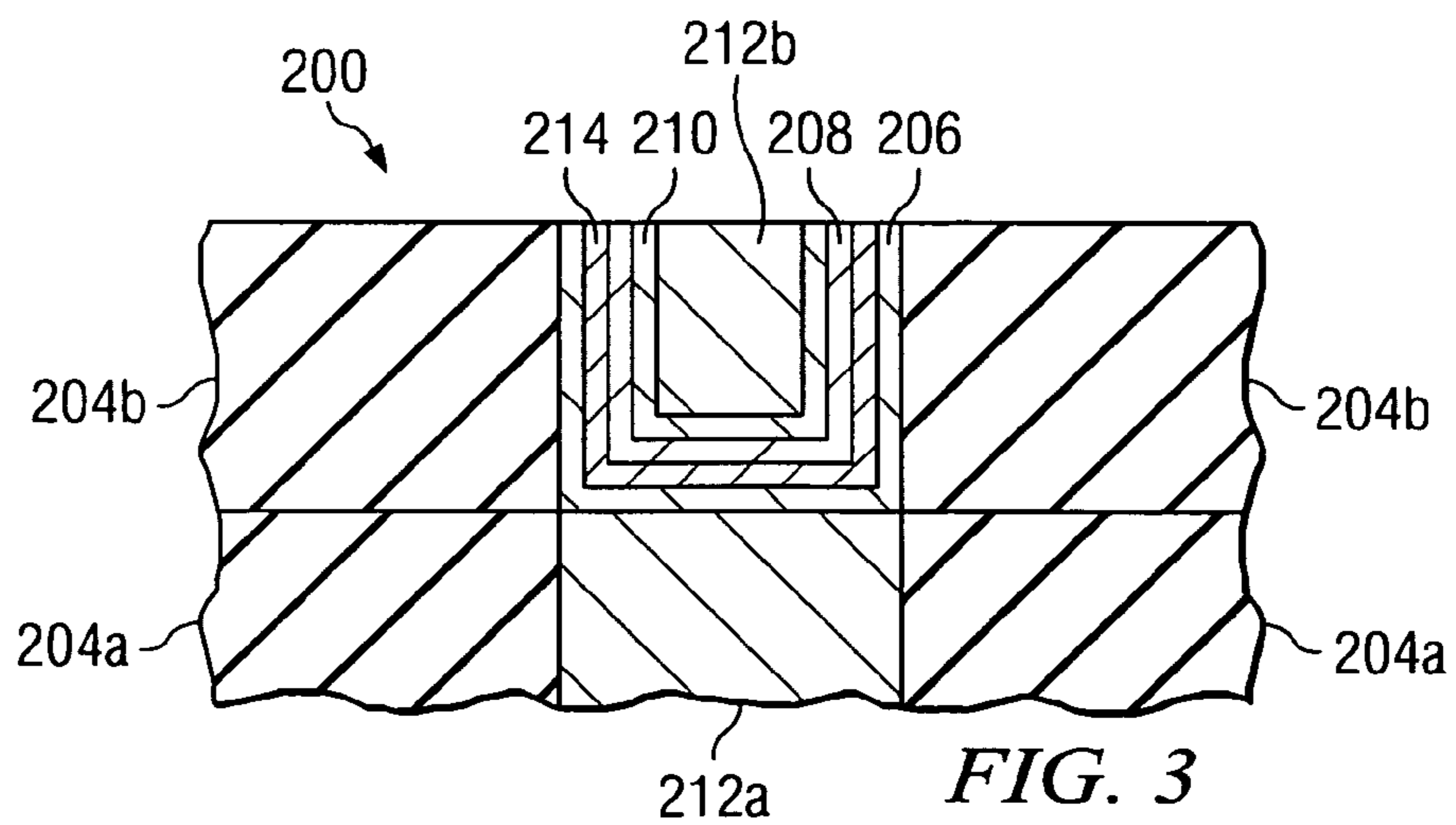
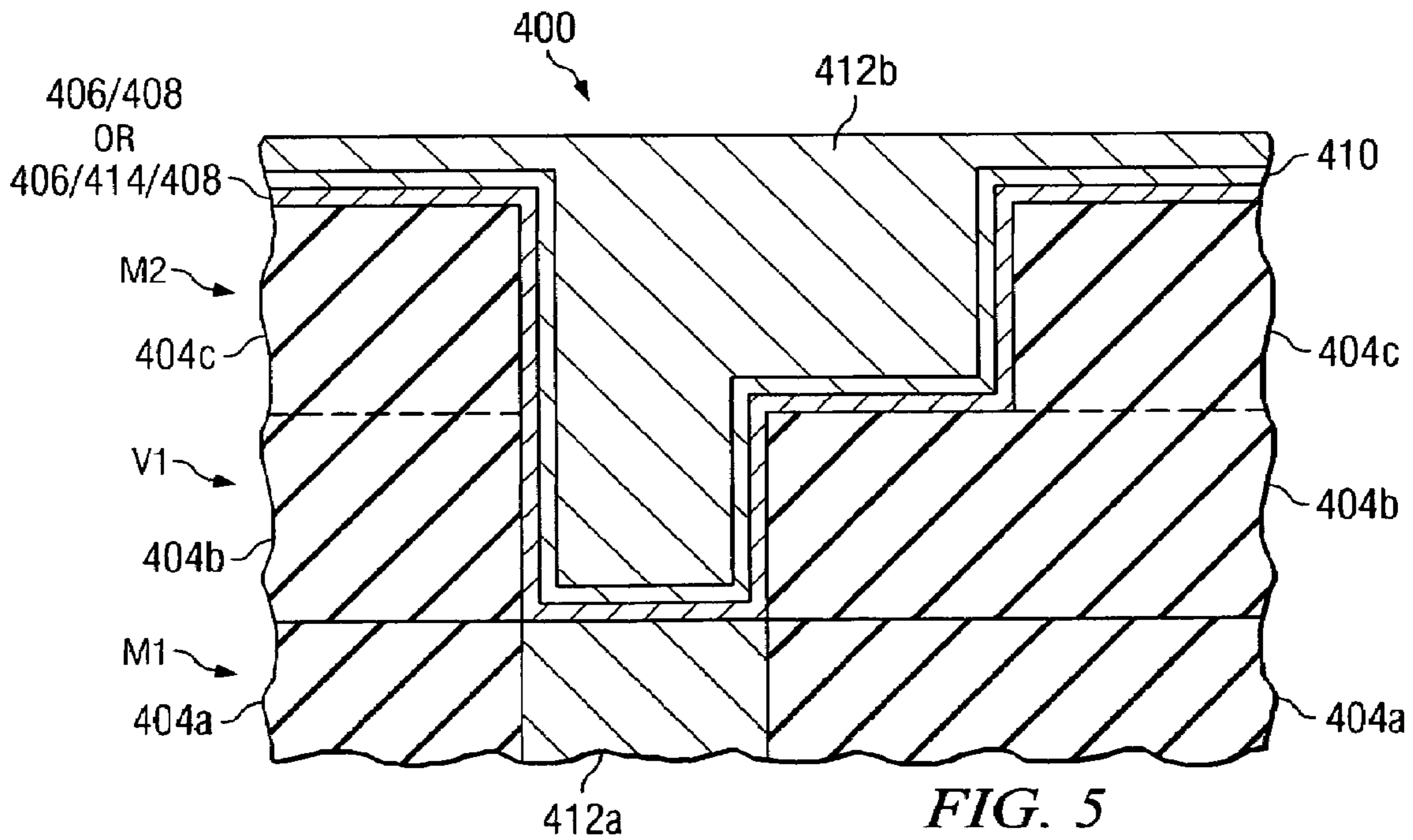
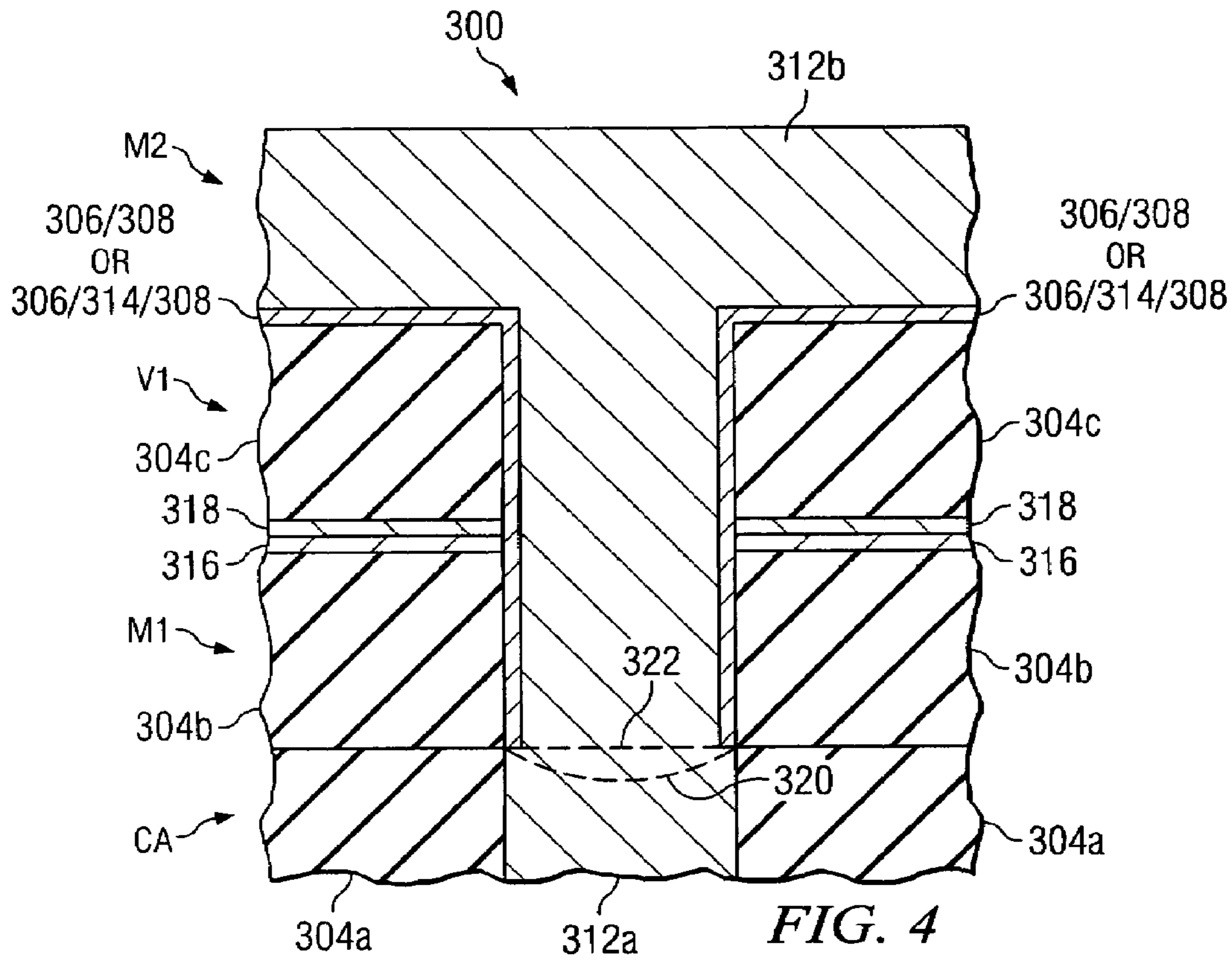


FIG. 3





## 1

SEMICONDUCTOR DEVICES AND  
METHODS OF MANUFACTURE THEREOF

## TECHNICAL FIELD

The present invention relates generally to the fabrication of semiconductors, and more particularly to structures and methods of forming barrier layers of semiconductor devices.

## BACKGROUND

Generally, semiconductor devices are used in a variety of electronic applications, such as computers, cellular phones, personal computing devices, and many other applications. Home, industrial, and automotive devices that in the past comprised only mechanical components now have electronic parts that require semiconductor devices, for example.

Semiconductor devices are manufactured by depositing many different types of material layers over a semiconductor workpiece or wafer, and patterning the various material layers using lithography. The material layers typically comprise thin films of conductive, semiconductive, and insulating materials that are patterned and etched to form integrated circuits (IC's). There may be a plurality of transistors, memory devices, switches, conductive lines, diodes, capacitors, logic circuits, and other electronic components formed on a single die or chip.

In the past, aluminum was typically used as a conductive line material in integrated circuits. Silicon dioxide was typically used as the insulating material between the aluminum conductive lines. However, as semiconductor devices are scaled down in size, there is a trend towards the use of copper for an interconnect material, in conjunction with the use of low dielectric constant ( $k$ ) materials. Advantages of using copper for interconnects in integrated circuits include decreased resistivity, resulting in increased speed, decreased RC time delay, and the ability to form thinner conductive lines.

However, there are some challenges in working with copper in a manufacturing process. While aluminum may be subtractively etched, copper is difficult to subtractively etch, and thus, damascene processes are typically used to form copper conductive features. In a damascene process, a dielectric material is deposited over a wafer, and then the dielectric material is patterned with a conductive feature pattern. The conductive feature pattern typically comprises a plurality of trenches, for example. The trenches are then filled in with conductive material, and a chemical-mechanical polish (CMP) process is used to remove the excess conductive material from the top surface of the dielectric material. The conductive material remaining within the dielectric material comprises conductive features such as conductive lines or vias, as example.

Copper has a tendency to diffuse into adjacent material layers, such as the insulating layers the copper interconnects are formed in. Thus, diffusion barriers are sometimes used to prevent the diffusion of copper. Typical diffusion barrier materials are Ta and TaN, as examples. Because these materials have a higher resistance than copper, the diffusion barriers are typically deposited in a thin layer in order to avoid excessively increasing the resistance of conductive features. These thin conventional diffusion barriers have a tendency towards the formation of weak spots and holes, which may permit copper to diffuse into adjacent material layers, which causes device failures.

Furthermore, Ta and TaN barrier layers tend to form an oxide at the interface of some insulating materials, which

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increases the resistance. Particularly in lower metallization layers, thermal budget limits may result in oxidation of the barrier layers, which may result in increased effective dielectric constant ( $k_{eff}$ ) values and a higher capacitance, which increases an RC delay of conductive lines.

Thus, what are needed in the art are improved diffusion barrier layers and methods of formation thereof.

## SUMMARY OF THE INVENTION

These and other problems are generally solved or circumvented, and technical advantages are generally achieved, by preferred embodiments of the present invention, which provide improved methods of forming barrier layers and structures thereof.

In accordance with a preferred embodiment of the present invention, a method of forming a barrier layer includes providing a workpiece, forming a first material layer over the workpiece, the first material layer comprising a nitride-based metal compound, and forming a second material layer over the first material layer, the second material layer comprising Ta or Ti. The barrier layer comprises the first material layer and at least the second material layer.

The foregoing has outlined rather broadly the features and technical advantages of embodiments of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of embodiments of the invention will be described hereinafter, which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures or process for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGS. 1 and 2 show cross-sectional views of a semiconductor device at various stages of manufacturing in accordance with an embodiment of the invention, wherein a barrier layer comprises a first layer of HfN and a second layer of Ta or Ti disposed over the first layer of HfN;

FIG. 3 shows a cross-sectional view of a semiconductor device in accordance with another embodiment of the invention, wherein the barrier layer further comprises a layer of TaN or TiN disposed between the first layer of HfN and the second layer of Ta or Ti;

FIG. 4 shows a cross-sectional view of a semiconductor device in accordance with another embodiment of the invention, wherein the barrier layer is removed from a bottom surface of a trench before filling the trench with a conductive material;

FIG. 5 shows a cross-sectional view of a semiconductor device in accordance with another yet embodiment of the invention, wherein the barrier layer is implemented in a dual damascene structure; and

FIG. 6 shows a cross-sectional view of a semiconductor device in accordance with another embodiment of the inven-

tion, wherein the barrier layer is implemented in the formation of contacts in a back end of line (BEOL) manufacturing process.

Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the preferred embodiments and are not necessarily drawn to scale.

#### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the presently preferred embodiments are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

The present invention will be described with respect to preferred embodiments in a specific context, namely the formation of barrier layers over insulating material layers. The invention may also be applied, however, to the formation of barrier layers on other material layers, such as semiconductive materials or conductive materials, as examples.

Embodiments of the present invention achieve technical advantages by providing novel methods of forming barrier layers having improved properties, such as improved diffusion prevention and increased resistance to oxidation, as examples.

FIGS. 1 and 2 show cross-sectional views of a semiconductor device **100** at various stages of manufacturing in accordance with an embodiment of the invention. Referring first to FIG. 1, the semiconductor device **100** includes a workpiece **102**. To manufacture the device **100**, first, the workpiece **102** is provided. The workpiece **102** may include a semiconductor substrate comprising silicon or other semiconductor materials covered by an insulating layer, for example. The workpiece **102** may also include other active components or circuits, not shown. The workpiece **102** may comprise silicon oxide over single-crystal silicon, for example. The workpiece **102** may include other conductive layers or other semiconductor elements, e.g., transistors, diodes, etc. Compound semiconductors, GaAs, InP, Si/Ge, or SiC, as examples, may be used in place of silicon. The workpiece **102** may comprise a silicon-on-insulator (SOI) substrate, for example.

A material layer **104** is formed over the workpiece **102**. The material layer **104** may comprise conductive, insulative, or semiconductive materials, for example. In one embodiment of the invention, the material layer **104** preferably comprises an insulating material layer **104**, for example. The insulating material layer **104** preferably comprises insulating materials typically used in semiconductor manufacturing for inter-level dielectric (ILD) layers, such as SiO<sub>2</sub>, tetra ethyl oxysilane (TEOS), fluorinated TEOS (FTEOS), spin-on glass (SOG), SiN, SiON, or low k insulating materials, e.g., having a dielectric constant of about 4 or less, or combinations or multiple layers thereof, as examples, although alternatively, the material layer **104** may comprise other materials. The insulating material layer **104** may comprise dense SiCOH or a porous dielectric having a k value of about 3 or lower, as examples. The insulating material layer **104** may also comprise an ultra-low k (ULK) material having a k value of about 2.3 or lower, for example.

The insulating material layer **104** may comprise a thickness of about 500 nm or less, for example, although alternatively, the insulating material layer **104** may comprise other

dimensions. The insulating material layer **104** may have been previously patterned using lithography, as shown, e.g., in a damascene process, although alternatively, the material layer **104** may be planar and unpatterned (not shown in the Figures). The insulating material layer **104** may be patterned using a reactive ion etch (RIE) and ash process, for example, followed by a damage recovery process, such as a wet etch and/or silylation, as examples, although other etch processes may also be used to pattern the insulating material layer **104**.

A barrier layer **106/108** is formed over the insulating material layer **104**. The barrier layer **106/108** is formed by first forming a first material layer **106** over the insulating material layer **104**, and over exposed portions of the workpiece **102**, if the insulating material layer **104** has been patterned, as shown. Note that embodiments of the present invention are also useful in applications where a material layer such as insulating material layer **104** has not been patterned; e.g., wherein the insulating material layer **104** is planar (not shown in the figures).

The first material layer **106** preferably comprises a nitride-based metal compound. In a preferred embodiment, the first material layer **106** preferably comprises HfN, for example. The first material layer **106** may also comprise other nitride-containing materials, such as other nitride-containing high k materials having a dielectric constant or k value greater than the dielectric constant of SiO<sub>2</sub>, e.g., insulating materials comprising nitride having a dielectric constant of about 3.9 or greater. The first material layer **106** may also comprise other transition metal nitride materials, for example. The first material layer **106** comprises an anti-oxidation layer in some embodiments, for example.

The first material layer **106** in some embodiments preferably comprises a material comprising [a, b]<sub>x</sub>N<sub>y</sub>, wherein the elements a and b preferably comprise a metal component. Elements a and b preferably comprise elements within columns IVb, Vb, or VIb of the periodic table, for example. Elements within these columns of the periodic table form good metallic nitrides for use in some embodiments of the present invention, for example. The first material layer **106** preferably comprises one or more elements within column IVb, Vb, or VIb combined with nitride. In some embodiments, the first material layer **106** preferably comprises a ternary compound of two elements within columns IVb, Vb, or VIb combined with nitride, for example. Preferably, in some embodiments, the first material layer **106** comprises either one element or two elements from columns IVb, Vb, or VIb of the periodic table combined with nitride.

The first material layer **106** preferably comprises a thickness of about 100 Angstroms or less, and more preferably comprises a thickness of about 5 to 50 Angstroms in some embodiments, for example. In some embodiments, the first material layer **106** preferably comprises a monolayer of HfN, for example. In these embodiments, the first material layer **106** may comprise a thickness of about 10 Angstroms or less, or more preferably, comprises about 6 Angstroms or less, for example.

The first material layer **106** comprised of HfN is preferably deposited by atomic layer deposition (ALD), for example, although alternatively, the first material layer **106** may be formed using other methods. The first material layer **106** may alternatively be formed by physical vapor deposition (PVD), as an example. In some embodiments, the first material layer **106** may comprise a single atomic layer or multiple atomic layers of HfN, for example. The first material layer **106** is preferably substantially conformal, e.g., the first material layer **106** preferably conforms to the underlying topography

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of the material layer **104**, lining the top surface and sidewalls and the exposed top surface of the workpiece **102**.

Next, a second material layer **108** is formed over the first material layer **106**. The second material layer **108** preferably comprises Ta or Ti in accordance with preferred embodiments of the present invention. The second material layer **108** is preferably deposited by ALD or PVD, as examples, although other deposition methods may also be used to form the second material layer **108**. The second material layer **108** preferably comprises a thickness of about 100 Angstroms or less, although alternatively, the second material layer **108** comprised of Ta or Ti may comprise other dimensions, for example.

In some embodiments, the first material layer **106** and second material layer **108** are formed in situ, e.g., in the same processing chamber (not shown), preferably without removing the workpiece **102** from the processing chamber, for example. In some embodiments of the present invention, for example, the workpiece **102** is placed in a first chamber prior to the deposition of the first material layer **106** of the barrier layer **106/108**, and the workpiece **102** is not removed from the first chamber until the first material layer **106** and second material layer **108** are formed over the workpiece **102**, for example. In other embodiments, for example, the workpiece **102** is exposed to a vacuum while in the first chamber, and the vacuum is not removed until after all of the barrier materials **106** and **108** (and the optional third material layer **214** shown in FIG. **3**, to be described further herein) have been formed over the workpiece **102**, for example.

A seed layer **110** is formed over the second material layer **108** of the barrier layer **106/108**, as shown in FIG. **1**. The seed layer **110** preferably comprises copper in one embodiment, for example, although the seed layer **110** may alternatively comprise other materials. The seed layer **110** may comprise a thickness of about 500 Angstroms or less, for example, although the seed layer may also comprise other dimensions. The seed layer **110** may comprise pure copper that is adapted to facilitate in the deposition of a subsequently deposited conductive material **112**, for example. The seed layer **110** preferably comprises a metal adapted to promote plating properties of a subsequently-formed conductive material **112**, for example. The seed layer **110** preferably comprises a metal, for example, in some embodiments.

A conductive material **112** is then formed over the seed layer **110**, as shown in FIG. **1**. The conductive material **112** preferably comprises copper in some embodiments, although alternatively, the conductive material **112** may comprise copper, aluminum, tungsten, or combinations or alloys thereof, as examples, or other materials. The conductive material **112** may be formed by electroplating, for example, although other deposition techniques may also be used to form the conductive material **112**. The conductive material **112** is also referred to herein as a conductive fill material, for example.

Excess conductive material **112**, seed layer **110**, second material layer **108**, and first material layer **106** are then removed from over the top surface of the insulating material layer **104** e.g., using a CMP process, leaving conductive features comprised of the conductive material **112**, seed layer **110**, and the barrier layer **106/108** formed in the patterns in the insulating material layer **104**.

FIGS. **3**, **4**, and **5** show additional preferred embodiments of the present invention. Like numerals are used for the various elements that were described in FIGS. **1** and **2**. To avoid repetition, each reference number shown in FIGS. **3**, **4**, and **5** is not described again in detail herein. Rather, similar materials **x02**, **x04**, **x06**, **x08**, etc. are preferably used for the various material layers shown as were described for FIGS. **1**

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and **2**, where  $x=1$  in FIGS. **1** and **2**,  $x=2$  in FIG. **3**,  $x=4$  in FIG. **5**, and  $x=5$  in FIG. **6**. As an example, the preferred and alternative materials and dimensions described for the first material layer **106** and the second material layer **108** of the barrier layer **106/108** in the description for FIGS. **1** and **2** are preferably also used for the material layers **206** and **208** shown in FIG. **3**.

FIG. **3** shows a cross-sectional view of a semiconductor device **200** in accordance with another embodiment of the invention, wherein the barrier layer **206/214/208** further comprises a third material layer **214** disposed between the first material layer **206** and the second material layer **208**. The third material layer **214** preferably comprises a layer of TaN or TiN disposed between the first material layer **206** of HfN and the second material layer **208** of Ta or Ti.

In this embodiment, after forming the first material layer **206**, the third material layer **214** is preferably deposited using ALD or PVD directly over and abutting the first material layer **206** comprised of HfN. The third material layer **214** preferably comprises a thickness of about 100 Angstroms or less, for example. Alternatively, the third material layer **214** may be deposited using other methods and may comprise other dimensions, for example. In this embodiment, the second material layer **208** is preferably deposited directly over and abutting the third material layer **214** that is disposed over the first material layer **206**, as shown.

If the optional third material layer **214** comprising TaN or TiN is included, preferably the third material layer **214** is disposed between the first material layer **206** comprising HfN and the second material layer **208** comprising Ta or Ti. In some applications, e.g., wherein the conductive fill material **212** comprises copper, the second material layer **208** that may comprise Ta is preferably used that is adapted to prevent diffusion of copper (e.g., the conductive fill material **212**) into adjacent material layers, for example.

In the example shown in FIG. **3**, the workpiece (not shown in FIG. **3**; see FIGS. **1** and **2**) may include a first insulating material layer **204a** formed at a top surface thereof, as shown. The first insulating material layer **204a** may comprise a first ILD layer in which conductive features such as conductive line **212a** have been previously formed, for example. A second insulating material layer **204b** is deposited over the first insulating material layer **204a** and conductive line **212a**. The second insulating material layer **204b** may comprise a second ILD layer, for example. The second insulating material layer **204b** is patterned with a plurality of trenches for conductive features. The pattern for at least one of the trenches may be disposed directly over the conductive feature **212a** in the underlying insulating material layer **204a**, as shown.

The novel barrier layer **206/214/208** of embodiments of the present invention is formed over the patterned second insulating material layer **204b**, lining the trenches in the second insulating material layer **204b** and the exposed top surfaces of the conductive line **212a**. A seed layer **210** is formed over the barrier layer **206/214/208**, and a conductive fill material **212b** is formed over the seed layer **210**, as shown. Excess conductive fill material **212b**, seed layer **210**, and barrier layer **206/214/208** are removed from over the top surface of the second insulating material layer **204b**, e.g., using a CMP process and/or etch process, leaving the structure shown in FIG. **3**. Processing of the semiconductor device **200** is then continued, e.g., by depositing additional insulating material layers and forming conductive features therein, not shown.

In the embodiment shown in FIG. **3**, the barrier layer **206/214/208** is left residing over the top surface of the underlying conductive feature **212a** before the seed layer **210** and conductive material layer **212b** are formed. The barrier layer

**206/214/208** materials are conductive and thus they be left remaining in the semiconductor device **200** over the conductive feature **212a** in some embodiments. However, in other embodiments of the present invention, the barrier layer **206/214/208** may comprise a higher resistance than the seed layer **210** and conductive fill material **212b**, and thus, it may be desirable in some applications to remove the barrier layer **206/214/208** from the top surface of the conductive feature **212a** before filling the trench with the seed layer and/or conductive fill material **212b**. This may be achieved using an anisotropic etch process of the barrier layer **206/214/208** before the seed layer and/or conductive fill material **212b** are formed, for example.

The barrier layers **106/108** and **206/214/208** shown in FIGS. **2** and **3** have improved barrier properties. The barrier layers **106/108** and **206/214/208** prevent diffusion of the materials such as copper in the seed layers **110** and **210** and conductive fill materials **112** and **212b** into adjacent insulating material layers, such as insulating material **104** or the workpiece **102** in FIG. **2**, or into insulating materials **204b** and **204a** in FIG. **3**.

The first material layer **106** and **206** of the barrier layers **106/108** and **206/214/208**, respectively, advantageously comprises HfN. HfN has excellent anti-oxidation properties and exhibits excellent qualities when applied to an oxide, e.g., after thermal treatments such as rapid thermal anneal processes. HfN has a low enthalpy change  $\Delta H$  of oxidation at an ILD interface. Preferably, the first material layer **106** and **206** comprising HfN is extremely thin and the formation thereof using ALD is well-controlled, so that conductive features formed using the novel barrier layers **106/108** or **206/214/208** achieve a low series resistance  $R_s$  value and a low parasitic capacitance.

The embodiments shown in FIGS. **1**, **2**, and **3** illustrate single damascene methods of forming conductive features of a semiconductor device **100** or **200**. In a single damascene process, a single layer of insulating material **104** or **204b** is patterned with a pattern for conductive features, such as conductive lines, conductive vias, or contacts, as example. Embodiments of the present invention may also be implemented in dual or multiple damascene processes, wherein two or more insulating material layers are patterned with patterns for conductive features and are later filled in a single fill step with a conductive material.

FIG. **4** shows a cross-sectional view of a semiconductor device **300** in accordance with another embodiment of the invention, wherein the novel barrier layer **306/308** or **306/314/308** is implemented in a dual damascene structure. In this embodiment, the barrier layer is removed from a bottom surface of a trench **322** before filling the trench with a conductive material **312b**.

In this embodiment, a multi-layer interconnect structure is shown. The workpiece (not shown) includes a first insulating material layer **304a** comprising a contact CA layer disposed proximate a top surface thereof. Conductive features **312a** may be formed in a first CA or metallization layer of the semiconductor device, comprised of a conductive material **312a** such as copper, for example.

A second insulating material layer **304b** comprising an ILD material is formed over the first insulating material layer **304a**. One or more optional thin insulating material layers **316** and **318** may be deposited over the second insulating material layer **304b**. The thin insulating material layers **316** and/or **318** may comprise etch stop layers and/or barrier layers, for example. In one embodiment, the thin insulating material layer **316** may comprise a hard mask such as TEOS,

and the thin insulating material layer **318** may comprise a cap layer such as CoWP, as examples, although other insulating materials may also be used.

A third insulating material layer **304c** comprising an ILD material is deposited over the thin insulating material layer **318**. The third insulating material layer **304c** and the second insulating material layer **304b** are patterned, e.g., a pattern for conductive lines may be formed in the second insulating material **304b** in the M1 layer, and a pattern for vias may be formed in the third insulating material **304c**. The novel barrier layer **306/308** or **306/314/308** described herein with reference to FIGS. **1**, **2**, and **3** is formed over the patterned insulating material layers **304b** and **304c**. Note that a seed layer (not shown) may be formed over the barrier layer **306/308** or **306/314/308** prior to forming the conductive material **312b**.

In this embodiment, the barrier layer **306/308** or **306/314/308** is anisotropically etched, e.g., using an etch process adapted to remove the barrier layer **306/308** or **306/314/308** material more rapidly or preferentially on top surfaces of the semiconductor device **300** than on sidewalls of features, e.g., within the trenches. Preferably, all of the barrier layer **306/308** or **306/314/308** material is removed from over the bottom **322** of the trenches. In some embodiments, the anisotropic etch of the barrier layer **306/308** or **306/314/308** may result in forming a recess **320** in the top surface of the underlying conductive features **320**, as shown in phantom in FIG. **4**, for example.

The various insulating material layers **304a**, **304b**, **304c** may comprise metallization layers in a multi-level interconnect structure of the semiconductor device **300**, as shown. For example, insulating material layer **304a** and conductive feature **312a** may comprise a CA or contact layer; insulating material layer **304b** and a portion of conductive material **312b** may comprise a first metallization layer M1; and insulating material layer **304c** and a portion of the conductive material **312b** may comprise a first via layer V1. Additional interconnect layers such as M2 may be formed over the interconnect layers CA, M1, and V1 shown, for example, after the CMP of excess conductive material **312b** and barrier layer **306/308** or **306/314/308** from over the top surface of the insulating material layer **304c**.

In some embodiments, an anisotropic etch process of the barrier layer **306/308** or **306/314/308** may be performed after the formation of the HfN-containing first material layer **306**, not shown. The first material layer **306** is removed from the bottom **322**, and optionally, the underlying conductive material **312a** may be recessed during the anisotropic etch process, as shown at **320**. Then, the second material layer **308**, or the third material layer **314** and also the second material layer **308**, may be formed over the exposed conductive material **312a** at the bottom of the trench, and over the first material layer **306** on the sidewalls of the trenches, for example.

FIG. **5** shows a cross-sectional view of a semiconductor device **400** in accordance with another yet embodiment of the invention, wherein the barrier layer **406/408** or **406/414/408** is implemented in a dual damascene structure. In this embodiment, patterns for vias are formed in a second insulating material layer **404b**, and patterns for conductive lines are formed in a third insulating material layer **404c** disposed over the second insulating material layer **404b**. The barrier layer **406/408** or **406/414/408** is formed over the patterned second insulating material layer **404b** and third insulating material layer **404c**, a seed layer **410** is formed over the barrier layer **406/408** or **406/414/408**, and the remainder of the patterns in the second insulating material layer **404b** and third insulating material layer **404c** are simultaneously filled in a single fill process with the conductive fill material **412b**, forming vias in



the patterned second insulating material layer **404b** and forming conductive lines in the third insulating material layer **404c**.

FIG. 6 shows a cross-sectional view of a semiconductor device **500** in accordance with yet another embodiment of the invention. In this embodiment, the novel barrier layer **506/508** or **506/514/508** is implemented in the formation of contacts in a back end of line (BEOL) manufacturing process. Transistors **538** and other devices (not shown) are formed in a front end of the line (FEOL) process, within and over a workpiece **502**. The transistors **538** may include active areas **532** such as source and drain regions formed within the workpiece **502**. The transistors **538** may include a gate dielectric **536** and a gate **542** disposed over the gate dielectric **536**. A portion **540** of the transistor gates **542** may be silicided, and a portion **534** of the source or drain regions **532** of the transistors **538** may also be silicided, as shown in phantom.

The insulating material layers **504a**, **504b**, **504c**, **504d**, and **504e** of the multi-level interconnect structure may be patterned as needed to provide electrical contact to underlying devices. The novel barrier layer **506/508** or **506/514/508** described herein is formed over at least sidewalls of the patterned insulating material layers **504a**, **504b**, **504c**, **504d**, and **504e**, and a conductive fill material **512** is deposited over the barrier layer **506/508** or **506/514/508**. For example, in region **530a** of the semiconductor device **500**, a conductive line **512** formed in metallization layer **M1** makes electrical contact to a silicide region **534** of a source or drain region **532** of a transistor **538**. Likewise, in region **530b** of the semiconductor device **500**, a conductive line formed in metallization layer **M2** makes electrical contact to a silicide region **540** of a gate **542** of a transistor **538**.

The embodiment shown in FIG. 5 is advantageous because the novel barrier layer **506/508** or **506/514/508** enables the ability to form contacts comprised of copper. In conventional semiconductor devices, tungsten (W) was used for the material of contacts, which has an increased resistance compared to copper. Furthermore, W as a contact material can result in void formation in the fill process, higher electromigration resistance and increased defects. Thus, the use of the barrier layers **506/508** or **506/514/508** and copper as a conductive fill material **512** result in lower resistance contacts, improved device quality, improved electromigration resistance, and decreased device defects. Contacts having a lower total series resistance  $R_s$  value can be achieved, e.g., by controlling the amount of a recess in an underlying conductive material (e.g., into the silicide **540** or **534**), and by controlling the thickness of the second material layer **508**, for example.

Embodiments of the present invention include semiconductor devices **100**, **200**, **300**, **400**, and **500** manufactured in accordance with the methods described herein.

Advantages of embodiments of the invention include providing improved barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** and methods of formation thereof. The novel barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** provide improved diffusion prevention and have increased oxidation resistance. The barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** have a high level of thermal stability and anti-oxidation properties.

The novel barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** provide a reliable and high performance barrier layer that is thermally stable, even at very small thicknesses. Using a HfN-containing first material layer **106**, **206**, **306**, **406**, and

**506** with a Ta or Ti layer (second material layer **108**, **208**, **308**, **408**, or **508**) disposed directly over and abutting thereon, or also with a TaN or TiN layer (third material layer **214**, **314**, **414**, or **514**) disposed between and directly abutting both the first material layer **106**, **206**, **306**, **406**, and **506** and the second material layer **108**, **208**, **308**, **408**, or **508**, results in an excellent copper diffusion barrier layer **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** that maintains excellent barrier properties even at high temperatures, such as after being exposed to a rapid thermal anneal (RTA) at about 1,000° C. for about 1 minute, as an example.

The barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** are adapted to repeatedly sustain BEOL thermal budgets in multi-level interconnect processes, for example. Thus, the barrier layers **106/108**, **206/214/208**, **306/308**, **306/314/308**, **406/408**, **406/414/408**, **506/508**, and **506/514/508** maybe used as a barrier layer and process as a contact liner, followed by a copper plating process to form contacts in multi-level interconnect structures, as shown in FIG. 6, providing low resistivity void-free contacts. Because the resistance of the copper contacts is reduced, smaller contacts may be formed, allowing the ability to reduce the size of the contacts in interconnect structures and scale semiconductor devices.

Although embodiments of the present invention and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. For example, it will be readily understood by those skilled in the art that many of the features, functions, processes, and materials described herein may be varied while remaining within the scope of the present invention. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A method of forming a barrier layer, the method comprising:
  - providing a workpiece having a silicide material layer;
  - forming a first insulating material layer of a first metallization level over the silicide material layer;
  - forming a second insulating material layer of a second metallization level over the first insulating material layer, wherein the first and the second metallization levels comprise a metal or via level above the workpiece;
  - forming a trench in the first and the second insulating material layers, a bottom surface of the trench exposing the silicide material layer;
  - forming a mono-layer of HfN (hafnium nitride) lining the trench and in contact with the exposed silicide material layer;

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forming a metal nitride layer over the HfN mono-layer, wherein forming the metal nitride layer comprises forming a TaN or TiN layer in contact with said HfN mono-layer;  
 forming a metal layer over and in contact with the metal nitride layer, the metal layer comprising Ta or Ti, wherein the barrier layer comprises the HfN mono-layer, the metal layer and the metal nitride layer; and exposing the silicide material layer by removing the barrier layer from the bottom surface of the trench;  
 after exposing the silicide material layer, lining the metal layer with a conductive liner; and  
 filling the trench by depositing a conductive fill material on the conductive liner.

2. The method according to claim 1, wherein forming the HfN mono-layer comprises forming by atomic layer deposition (ALD) or physical vapor deposition (PVD).

3. The method according to claim 1, wherein forming the metal layer comprises forming the metal layer by atomic layer deposition (ALD) or physical vapor deposition (PVD).

4. The method according to claim 1, wherein providing the workpiece comprises providing an insulating layer, and further comprising patterning the insulating material layer before forming the HfN mono-layer, wherein forming the HfN mono-layer over the workpiece comprises forming the mono-layer over and abutting the patterned insulating material layer.

5. The method according to claim 1, wherein the HfN mono-layer comprises a thickness of about 100 Angstroms or less,

wherein the metal layer has a thickness of about 100 Angstroms or less of Ta or Ti and,

wherein forming the metal nitride layer comprises forming about 100 Angstroms or less of TaN or TiN.

6. The method according to claim 1, wherein the HfN mono-layer and the metal layer comprise a barrier layer that prevents a portion of the conductive material from moving into the patterned insulating material layer.

7. The method according to claim 1, wherein the HfN mono-layer has a dielectric constant  $k$  of greater than about 3.9.

8. A method of fabricating a semiconductor device, the method comprising:

providing a workpiece, the workpiece including a trench disposed within a first and a second insulating material layer of a first and a second metallization level, wherein the first and the second metallization levels comprise a metal or a via level, wherein a silicide material layer is disposed under the bottom surface of the trench;

forming a HfN (hafnium nitride) layer lining the trench, the HfN layer being in contact with the silicide material layer;

forming a metal layer over the HfN layer, the metal comprising Ta or Ti;

forming a metal nitride layer over the HfN layer such that said metal nitride layer is between and in contact with both said HfN layer and said metal layer; and

forming a conductive material over the metal layer.

9. The method according to claim 8, wherein forming the conductive material comprises forming a seed layer over the second layer, and forming a fill material over the seed layer.

10. The method according to claim 8, wherein forming the conductive layer comprises forming a copper layer.

11. The method according to claim 8, wherein forming the HfN layer and forming the metal layer is carried out in a first chamber, and wherein forming the conductive material com-

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prises forming the conductive material in the first chamber, without removing the workpiece from the first chamber after forming the metal layer.

12. The method according to claim 8, further comprising removing the conductive material, the metal layer, and the HfN layer from over a top surface of the second insulating material to form conductive features within the first and the second insulating material layers.

13. A method of fabricating a semiconductor device, the method comprising:

depositing an insulating material layer over a workpiece; patterning the insulating material layer with a pattern for at

least one trench, wherein patterning the insulating material layer with a pattern for at least one trench comprises forming a trench for forming a first via in a first via level, first metal lines in a first metal level, a second via in a second via level, and a second metal line in a second metal level, the trench landing on a transistor gate;

lining the at least one trench in the insulating material layer with a HfN (hafnium nitride) mono-layer;

lining a metal nitride layer over the HfN mono-layer;

lining the metal nitride layer with a metal layer of Ta or Ti;

lining the metal layer with a conductive liner; and

filling a remainder of the at least one trench in the insulating material layer with a conductive fill material over the conductive liner.

14. A method of fabricating a semiconductor device, the method comprising:

providing a workpiece having a silicide material layer formed thereon;

forming a first insulating material layer over the silicide material layer, the first insulating material layer being formed in a first metallization level;

forming a second insulating material layer over the first insulating material layer, the second insulating material layer being formed in a second metallization level, wherein the first and the second metallization levels comprise a level for metal lines or vias;

patterning the first and the second insulating material layers with a pattern for at least one trench;

lining the at least one trench in the first and the second insulating material layers with a HfN (hafnium nitride) layer;

forming a metal nitride layer over the HfN layer;

lining the metal nitride layer with a metal layer comprising Ta or Ti;

removing the HfN layer, the metal nitride and the metal layer from a top surface of the conductive material layer to expose the silicide material layer; and then

lining the metal layer with a conductive liner, the conductive liner contacting the exposed silicide material layer; and

forming an interconnect disposed within the first and the second metallization level by filling a remainder of the at least one trench in the first and the second insulating material layers with a conductive fill material over the conductive liner.

15. The method according to claim 14, wherein lining the HfN mono-layer with the metal layer comprises forming a layer of Ta or Ti directly over and abutting the HfN layer.

16. The method according to claim 14, wherein lining the HfN layer with the metal layer comprises forming said metal nitride layer from TaN or TiN deposited directly over and abutting the HfN layer, and then forming the metal layer of Ta or Ti directly over and abutting the layer of TaN or TiN.

17. The method according to claim 14, wherein removing the HfN layer and the metal layer from the top surface of the

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conductive material layer further comprises forming a recess in a portion of the underlying conductive material layer of the workpiece.

**18.** The method of claim **14**, wherein the first and the second metallization levels comprises level for metal lines. 5

**19.** The method of claim **14**, wherein the first metallization level comprises a first via level, wherein the second metallization level comprises a first metal line level, and wherein the method further comprises:

forming a third insulating material layer over the second insulating material layer, the third insulating material layer being formed in a second via level, and 10

forming a fourth insulating material layer over the third insulating material layer, the fourth insulating material layer being formed in a second metal line level, and

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patterning the third and the fourth insulating material layers with a pattern for the at least one trench, and

wherein forming an interconnect further comprises filling remainder of the at least one trench in the third and the fourth insulating material layers with the conductive fill material.

**20.** The method of claim **14**, wherein the silicide material layer is disposed on a source/drain region of a transistor.

**21.** The method of claim **14**, wherein the silicide material layer is disposed on a gate region of a transistor.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,713,866 B2  
APPLICATION NO. : 11/602885  
DATED : May 11, 2010  
INVENTOR(S) : Moon et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In Col. 12, line 51, claim 14, delete “suicide” and insert --silicide--.

Signed and Sealed this

Twenty-ninth Day of June, 2010

A handwritten signature in black ink that reads "David J. Kappos". The signature is written in a cursive style with a large initial 'D' and a stylized 'K'.

David J. Kappos  
*Director of the United States Patent and Trademark Office*